The use of Hybrid Computational Methods for Creating Intelligent Decision-Making Systems in Medicine

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Abstract. The problem of providing computer support for decision making in medicine is relevant due to the increasing information load on the doctor, the development of computer technologies. When making medical decisions, there is a lack of time, high dynamics of the course of diseases, a high cost of medical error, etc. This paper describes basic design principles of the first version of next-generation decision support system for providing personalized patients care based on patients' clinical and treatment data with the use of authors synergetic collective decision-making model and the methods of hybrid computational intelligence which allows us to increase significantly the quality of the results of solutions to complex medical problems in information variety and heterogeneity as well as to enhance decision-making by reducing losses from erroneous and irrelevant to the problem complexity individual solutions. The result of the implementation should be breakthrough successes in solving many epidemiological, diagnostic, therapeutic, prophylactic, social and economic problems.

Keywords: hybrid computational intelligence, mathematical modeling, system analysis, decision support system, problem-system, providing personalized patients, solutions to complex medical problems.

1 Introduction

In work [1] three concepts - "a synergetic model of collective decision-making [2],[4], [15]", "a decision support system [3],[5],[7]" and "a hybrid computational intelligence" - are considered together. The idea of such material presentation arose nine years ago [3]. But it was not possible to implement it in full before this edition. Now it turned out to be possible and relevant. Here is the reason why.

The synergetic model [1],[5] of collective decision-making simulates the multilingual character [1],[3] of solving complex applied problem-systems in medicine [2],[5], [7] on the one hand, and the social collective nature of decisions on the other.

Thus, a right team interaction, partnership and cooperation in solving complex applied problems in medicine "increase efficiency by at least 10%" [2],[6], which generates a synergistic effect when the inability of one is compensated by the skills and abilities of another member of the team.

Perhaps this is due to the knowledge and experience of experts solving certain parts of a complex problem in medicine [7]; knowledge and experience of the decision-maker who is able to combine individual solutions into one collective solution, interacting with experts.

Hybrid computational intelligence (HCI) [1],[2],[3] — is an instrument of synergetic artificial intelligence [2],[4] designed to simulate the effects of interaction, self-organization and adaptation observed in systems where the nature, people and technology are closely intertwined.

Joint consideration of three mentioned complex concepts opens the way to a promising engineering technology (the basics of which are presented in this article) in the field of creating applied intellectual decision-making systems in medicine of the new generation able to integrate diverse knowledge models (in the following – the heterogeneous model field [1], [2],[3]), and thus solving the problem of increasing the quality of the results of solutions to complex medical problems in the context of information variety as well as enhancing decision-making by reducing losses from erroneous and irrelevant to the problem complexity individual solutions.

2 Methods of research.

According to the law of requisite variety [1],[2],[3], only a various coordinated analytical activity, which elements in combination solve one problem, will make the result of decision-making qualitatively better. The specific nature of this work is consistent with the collective work of experts in small groups – the councils. Fig. 1 shows the conceptual model of collective decision-making by a small experts group (SEG).

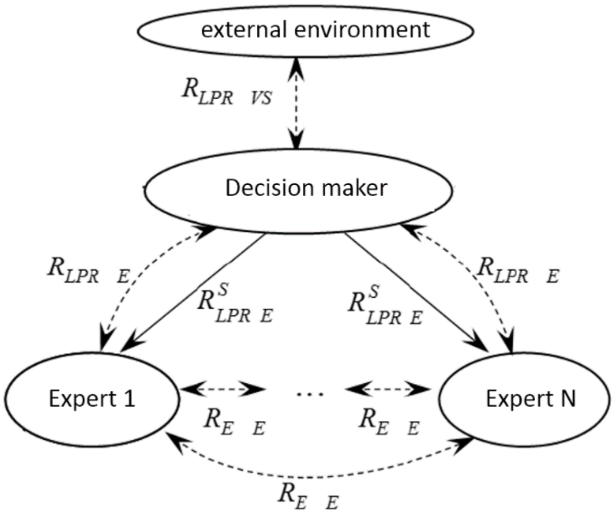

Fig. 1. The conceptual model of collective decision-making.

Notation: R_{LPR_VS}, R_{LPR_E} , R_{E_E} – are the information relations "external environment - decision maker", "expert - decision maker", "expert - expert", respectively; ${}^{S}R_{LPR\_VS}$ – is the cooperative relationship "decision maker - expert".

Advantages of SEG are focused on the implementation of ideas that are not feasible for individual decision-making, because the individual decision maker (DM) has no opportunity to go beyond his immediate activities. Professional duties in SEG are distributed in accordance with the abilities and competencies of performers, depending on the activity complexity. Synergetic effect in SEG is achieved by "the group compensation of individual disabilities [3]". The team interaction, partnership and cooperation in solving complex applied problems "increase efficiency by at least 10%" [2], [3], which generates a synergistic effect in SEG when the inability of one is compensated by the skills and abilities of another member of the team. Hence the methods of providing SEG collective solution on the basis of private expert advice are relevant [1]: Delphi method [1], hierarchy analysis method [1], brainstorming method [1], method of brain record pool [1], etc.

SEG simulation and the resulting synergy are encouraged to implement using HIMAS [6], which are hybrid intelligent systems (HIS), practicing multi-agent approach [6]. Elements of such HIS are realized in the form of agents having the property of autonomy [6]. Like multi-agent systems (MAS), they simulate the interactions of autonomous agents with each other and with the external environment, as a result of which the system architecture can be dynamically reconfigured in accordance with the specific functions (roles) of agents and the relationships established between them. As a result, HIMAS combines the positive aspects of HIS and MAS: because of the combination of several methods of artificial intelligence, they are relevant to problems with high simulation complexity [3],[6],[7]; due to the simulation of the interaction of experts and the resulting collective processes, they are able to change their architecture to achieve a synergistic effect. For computer realization of the SEG model, the HIMAS functional structure is developed (Fig. 2) [6].

The functional structure shown in Fig. 2. can be used in the design of HIMAS for a wide range of applied problems, because:

(1) a general multi-agent model of reality is used;

(2) a list of solver agents covers five classes of basic methods of artificial intelligence used in HIS [2,3];

(3) an order of agent interaction is determined by the subject domain model [2],[3],[6].

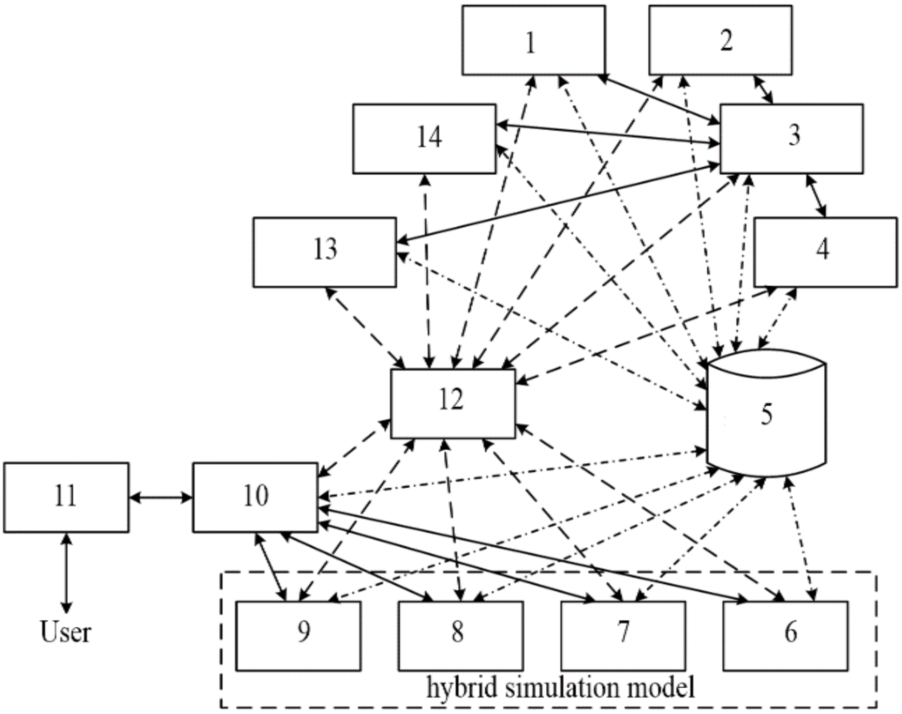

Fig. 2. The functional structure of the hybrid intelligent multi-agent system (HIMAS [6]), 1 - Logical agent, 2 - Fuzzy agent, 3 - Converter agent, 4 - Linguistic agent, 5 - Subject domain model, 6 - Finding-solution agent 4, 7 - Finding-solution agent 3, 8 - Finding-solution agent 2, 9 - Finding-solution agent 1, 11 - Interface agent, 10 - Decision-making agent, 12 - Proxy agent, 13 - Analysis agent, 14- Stochastic agent

Let us consider the purpose of agents of the HIMAS functional structure shown in (see Fig1):

(1) the interface agent requests input data and returns the result;

(2) the decision-making agent distributes the problem specification to the finding-solution agents and determines the order of their interaction;

(3) the finding-solution agents perform generation and evaluation of solutions based on the subject domain knowledge.

(4) the proxy agent monitors the capabilities of registered agents of intellectual technologies (solvers). Agents refer to proxy agent to find out which of the solvers can help in solving the subproblem set before them;

(5) the solvers together with the converter agent implement the hybrid component of HIMAS, combining diverse knowledge, simulating the multilingual nature of the solution of complex applied problem-system;

(6) the subject domain model is the semantic network [2],[3],[6], the basis of agent interaction, built on the base of the conceptual model of the current problem [2],[3].

The central element of HIMAS shown in (see Fig.1) is a subsystem of "Hybrid computational intelligence (Decision-making agent, see Fig. 1)". The concept of the hybrid computational intelligence occurs when the decision maker in the Decision Support System (DSS) breaks up a single whole (see Fig. 1), i.e. the initial problem into its constituent parts, and entrusts the solution of subproblems to the experts. In the fig. 3 the model of the problem has a two-level representation: at the macrolevel - the problem as a whole and its properties; at the microlevel - a system of subproblems (light circles) and a coordinating problem (dark circle). A complex problem is a problem-system [2],[3], which includes interrelated domains of var parameters [1]: determinated, stochastic, linguistic, genetic ones, in which the cause-effect relationships of the experts arguments are specified by representations — analytical, statistical, expert, fuzzy, neural, genetic ones.

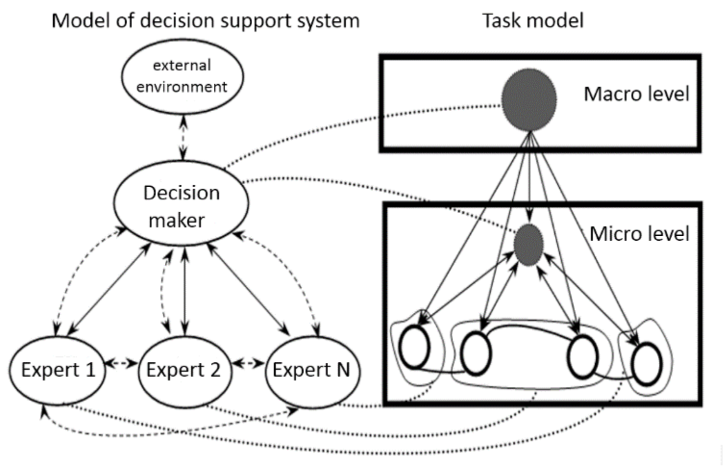

Fig. 3. Interaction of the DSS model and the problem model.

Macro- and microlevels are connected by reduction relations. If we consider the DSS model and the problem-system model together in (see Fig. 3), then a correspondence shown by dotted horizontal lines appears. DM solves the problem entirely and a coordinating problem, while the experts solve sub-problems grouped in the area of homogeneous parameters of the system-problem [1]. After receiving a part of the problem, the expert must understand it. One of the understanding stages is a realization of the reasoning technique that is the most suitable for solving the subproblem. To make a choice the expert should know the pros and cons of the reasoning techniques. Then the expert builds a model for solving the subproblem using the advantages of the technique. Cut and try, the choice of other methods and repeated reasoning are possible.

Fig. 4. shows the synergetic model of hybrid computational intelligence [2], which is characteristic of the collective decision-making model of SEG (see Fig. 1).

Experts who solve parts of the general problem-system (Fig. 3), create the parent models (see Fig. 4,*a*): $Model_1^P$,..., $Model_\kappa^P$, ..., $Model_f^P$,..., $Model_N^P$, and the variety of team work structures used in DSS (sequential, simultaneous, formation of subgroups, coalitions, etc.), i.e. the usage procedure of parent models for joint reasoning, determines the variety of descendant models: $Model_1^{\Pi}$, ..., $Model_N^{\Pi}$. These models relate to the general problem-system. The descendant models are the hybrids obtained on a heterogeneous model field [1],[3] by combining according to a functional feature, and inheriting the positive aspects of the reasoning methods applied by experts to solve parts of the original problem. We call such hybridization, obtained within the synergetic model of hybrid computational intelligence, a coarse-grained one [3].

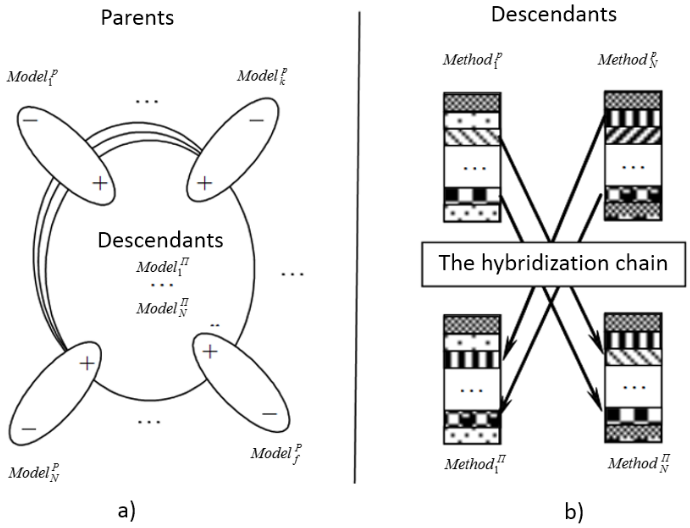

Fig. 4. Synergetic model of hybrid computational intelligence.

Fig. 4, *b* shows another pattern: the expert's sensation that none of the known prototype methods are suitable for solving the subproblem. This sensation arises when the expert is not satisfied with certain aspects of the methods. For example, one of them leads to models with intolerable error, but with good computational capabilities, and the other gives the opposite picture. The expert starts to consider the tool for solving the problem at different detail levels.

Fig. 5 shows a two-level representation of methods: at the macrolevel — the method as a whole; at the microlevel - the method decomposition using the "language — model — procedure" triad in combination with instrumental heterogeneity (decomposition of the procedure component into separate parts-grains).

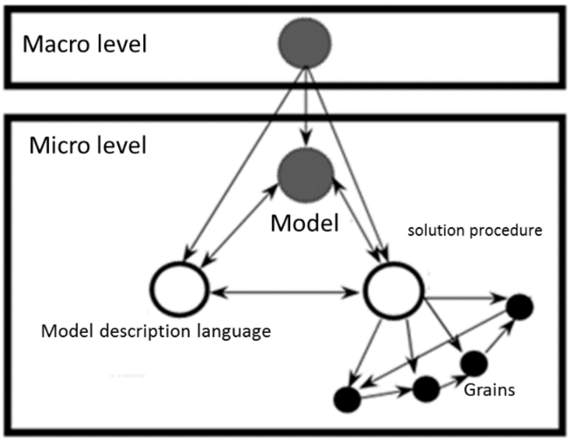

Fig. 5. Two-level model of hybrid computational intelligence.

At the macrolevel, the expert assesses the capabilities of the method as a single whole, and at the microlevel the method is represented as an entity consisting of separate parts. Macro- and microlevel aspects of the method are interdependent, their cause-effect relationships exist. It is important to know which modifications of the method parts at the microlevel lead to its desired properties at the macrolevel. And vice versa, how to combine and modify the method parts to obtain the desired properties.

Fig. 5 shows the classification of the cause-effect relationships of macrolevel properties of simulation methods and features of their microlevel construction. It uses the component parts of the method: "model", "description language", "solution procedure". Model — is representations (conceptual description of the subject domain), within which the method "works". Change of representations is a qualitative leap of the method properties from one class to another. The description language — is an alternative means to record a model, the form of its existence. The procedure — is an ordered set of actions (calculations) for finding solutions on the model. In a variety of methods of performing actions, a variety of their properties at the macrolevel is hidden.

Decomposition of the procedure component allows us to create sets of typical tools — grains, from which a tool for solving the problem is built during the hybridization.

This approach to the representation of the method allowed us to introduce the evolutionary model "the world of simulation methods" [3]. The methods of a certain class, defined by the model and the description language, form a niche in this world. Within that niche, there is a variety, determined by the variety of procedures for finding solutions. Change of model – is a change of a niche, and an occurrence of a new model, representation – is an occurrence of a niche. More often there is an accumulation of quantitative changes in the procedure part of the methods and their "drift" within one niche.

In (see Fig. 4,*b)* the methods are depicted on the microlevel, what is shown by the variety of their parts with different hatching. In order to achieve the desired macrolevel properties (hybridization chain), it is possible to combine the parts and obtain the descendant methods: $Method_1^{\Pi},..., Method_N^{\Pi}$. The descendant methods are hybrids obtained by combining according to the instrumental feature and inheriting the positive aspects of the reasoning methods used by the experts. We call the hybridization shown in (see Fig. 4,*b)*, a *fine-grained hybridization*.

In [3] the concept of "*hybridization direction*", consisting of two levels: 1)"from the problem"; 2) "from the method" is introduced. The point of the direction "from the problem" is that the problem should be considered at macro and microlevels. Macrolevel (problem phenotype) — defines the problem entirely as a complex entity, a system. The microlevel (complex problem genotype) is a set of subproblems, related in decomposition by the relation classes. Macro- and microlevel representations of the problem are interrelated and should be considered in unity. Hybridization "from the problem" requires: 1) research and extraction of knowledge about the macrolevel and microlevel representations of the problem; 2) research and extraction of knowledge about the interdependencies of macro- and microlevel representations.

The point of the direction "from the method" is that each method of a limited set should be considered at macro- and microlevel. The macrolevel (method phenotype) is a method entirely as a complex entity, a system. Microlevel (method genotype) is a set of grains "model", "description language", "solution procedure" or grains of a more detailed level as components of the decision procedure. Macro- and microlevel representations of the problem are interrelated and should be considered in unity. Hybridization "from the method" requires: 1) research and extraction of knowledge about the possibilities of methods; 2) research and extraction of knowledge about macrolevel and microlevel representations of methods; 3) research and extraction of knowledge about the interdependencies of macro- and microlevel method representations.

3 Approbation

To approbate the proposed solutions, the diagnostics problem of arterial hypertension (AH) was chosen - one of the most widespread diseases of the cardiovascular system. It is established that 20-30% of the world’s adult population suffer from arterial hypertension (WHO data). To study diagnostics problem of arterial hypertension (DPAH) the method of mixed reduction [8] was applied, based on the recommendations of the committee of experts of the Society of cardiology of Russian Federation (SCRF) and extraction of expert knowledge. Decomposition of DPAH including 12 diagnostics and 9 technological subproblems is constructed. Diagnostics subproblems grouped and indexed into nine areas of homogeneous parameters: target lesions, 11 risk factors of cerebrovascular diseases, metabolic syndrome and diabetes, diseases of the peripheral arteries, ischaemic heart disease, endocrine AH, parenchymal nephropathy and renovascular AH.

The method choice for computer-aided solution of diagnostics subproblems and analysis of instrumental heterogeneity of the hypertension diagnostics problems is made on three-quadrant matrix data model that contains "method–characteristics", "problem–characteristics" and "problem–method" knowledge [2],[4], what allowed us to set and explore the correspondence on sets of diagnostics subproblems and basic methods. The general, qualitative characteristics of the methods were taken into account to ensure the required functionality of the system entirely. As a result, the developed heterogeneous model field consists of 14 functional models: two artificial neural networks, nine fuzzy systems, two expert systems and technological models: nine genetic algorithms.

Fig. 6 shows an example of the functional scheme of the HIMAS hybrid computational intelligence subsystem (see Fig. 2) of arterial hypertension diagnostics, based on the model of artificial neural network of ECG recognition and the fuzzy system model of ischaemic heart disease diagnostics [8].

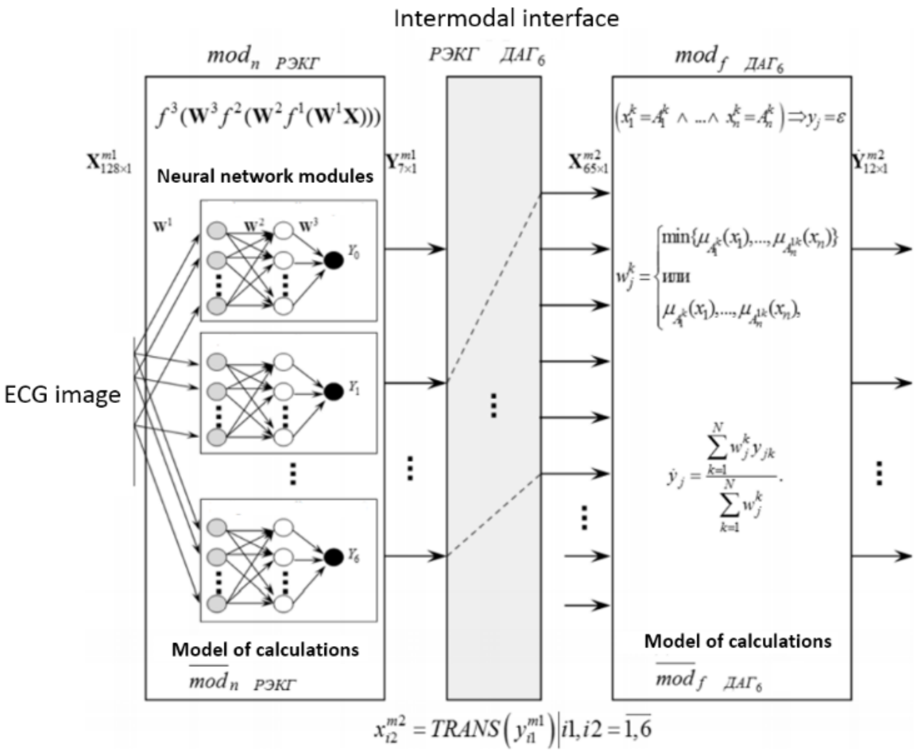

Fig. 6. The functional scheme of the HIMAS hybrid computational intelligence subsystem.

Notation: $X^{m1}_{128\times1}$ – is a 128×1 matrix of input vector of the modular artificial neural network model of ECG recognition; $Y^{m1}_{7\times1} = (Y_0,...,Y_6)^{tr}$ – is a 7×1 matrix of output vector $\mathrm{mod}_{РЭКГ}$;– f_1, f_2, f_3 operators of the logistic function of the input, hidden and output layers activation; w_1, w_2, w_3 – are the synaptic weights matrices of the input, hidden and output layers; $ДАГ_6$ – is an interface for information exchange between models that solve the subproblem of ECG recognition and ischaemic heart disease diagnostics; TRANS – is a conversion procedure; $(x_1^k = A_1^k \wedge ... \wedge x_n^k = A_n^k) \Rightarrow y_i = \varepsilon$ – is a fuzzy rule; k – is the rule number in the knowledge base; $\wedge$ – is the logical operation AND; ε – is the logical value (1 - true, 0 - false); $j = 1, N_Y; w_j^k$ – is the result of aggregation with min-conjunction; $\mu_A(x)$ – the membership functions.

Laboratory experiments with the HIMAS-AH prototype (a hybrid intellectual multi-agent system for arterial hypertension diagnostics developed within the grant of the Russian Foundation for Basic Research (RFBR project No. 16-07-00272)) produced the following results:

1. With the use of HIMAS-AH, the total time of the examination and result processing is approximately 30 seconds, which is seven times less than the diagnostics time when experienced doctors work together with a nurse;

2. A standard deviation in the diagnosis, based on the use of HIMAS-AH, was f = 0,0837, i.e. HIMAS-AH gives a reliable diagnosis in 92% of cases. Thus, the use of HIMAS-AH on the basis of fine-grained hybridization (see Fig. 4. b) gives better results than with a homogeneous approach, for example, the well-known "Diagnosis" project [8] - a system with a knowledge base to support decision making on AH diagnostics using logical-linguistic methods with the R. Carnap confidence factors method, which only in 60% of cases formed a right detailed differential diagnosis.

Conclusion

The tradition of complex problem solving by expert teams led by the DM, has old roots: military councils, collegium of Ministry, all kinds of meetings, briefings, concilia, think tanks etc. [12],[13],[14]. The urgency of the collective problem solving is due to the advantages over the individual manager's work: improving the quality of decisions by taking into account the variety of opinions and integrating the knowledge of various specialists; increasing confidence of all collective members in the results of its work and motivation to implement such decisions; compliance with ethical standards. Experienced decision-makers provide conditions for the emergence of positive group effects and minimize negative ones, rearranging the composition and structure of the control system, adapting to changes in the external environment. The problem is that most of modern computer technology is the medium for implementing methods, and not an instrument for their synthesis. Hence, similar to computer expert systems [1],[9],[10], arguing "no worse" than one person, the information technologies are not worse than the collective of specialists for management in the conditions of complex problems. The paper consider a promising approach in creating applied intellectual decision-making systems in medicine of the new generation, based on the authors synergetic collective decision-making model and the methods of hybrid computational intelligence, which allows us to increase significantly the quality of the results of computer-aided solutions to complex applied problems in information variety and heterogeneity as well as to enhance decision-making by reducing losses from erroneous and irrelevant to the problem complexity individual solutions, that is confirmed by the results of laboratory experiments with the hybrid intellectual multi-agent system for arterial hypertension diagnostics developed within the grant of the Russian Foundation for Basic Research (RFBR project No. 16-07-00272). The work in this direction continues intensively.

References

1. Klachek, P, Polupan, K, Koryagin, S, Lieberman, I: Hybrid Computing Intelligence. Part 1. Fundamentals of the theory and technology of creating applied systems. Publishing house of the Baltic Federal University of Immanuel Kant, Kaliningrad (2018).
2. Klachek, P, Koryagin, S, Lizorkina, O: Intellectual Systems Engineering. Publishing house of the Baltic Federal University of Immanuel Kant, Kaliningrad (2015).
3. Klachek, P, Koryagin, S, Kolesnikov, A, Minkova, E: Hybrid Adaptive Intelligent Systems. Theory and development technology. Publishing house of the Baltic Federal University of Immanuel Kant, Kaliningrad (2011).
4. Kolesnikov, V, Kirikov, A: Methodology and Technology of Complex Tasks Solution by Methods of Hybrid Intellectual Systems. Publishing house of the Institute of Applied Informatics of the Russian Academy of Sciences, Moscow (2007).
5. Quaglini, S, Barahona, P, Andreassen, S: Artificial Intelligence in Medicine. Springer Publishers, Berlin (2001).
6. Koryagin, S, Klachek, P: The Development of Hybrid Intelligent Systems on the Basis of Neurophysiological Methods And Methods of Multi-Agent Systems. In: IEEE First International Conference on Data Stream Mining & Processing, Lviv (2016).
7. Agah, A: Medical Applications of Artificial Intelligence. CRC Press, Florida (2017).
8. Rumovskaya S: Knowledge-based system for decision making support at diagnosing of the arterial hypertension. In: 9th Joint Conference on Knowledge-based Software Engineering, Kaunas, (2010).
9. Medsker, L:Hybrid Intelligent Systems. Kluwer Academic Publishers, Boston (1995).
10. Wermter, S., Sun, R: Hybrid Neural Systems. Springer-Verlag Publishers, Berlin (2000).
11. Rodrigues, M, Teixeira, A: Advanced Applications of Natural Language Processing for Performing Information Extraction. Springer-Verlag Publishers, Berlin (2015).
12. Castillo, O., Mellin, P: Hybrid Intelligent Systems. Springer-Verlag Publishers, Berlin, (2006).
13. Daniel, E. Knowledge-Management Systems: Converting and Connecting. Journal IEEE Intelligent systems (3), 30-33 (1998).
14. Negnevitsky, M: Artificial Intelligence. A guide to intelligent systems. Addison-Wesley Publishers, Harlow (2005).
15. Carlsson, G, FACP, Campion F: Machine Intelligence for Healthcare. CreateSpace Independent Publishing Platform, California (2017).